Example 6b: PATRAN Post-Processing

This example problem demonstrates how to obtain full access to all micro and macro field data that can be produced by MAC/GMC 4.0 for use in conjunction with the MSC/PATRAN software package. This enables the generation of fringe plots, which display the spatial variation of the predicted field components over the composite geometry. The MSC/PATRAN software is available from http://www.mscsoftware.com/. In order to generate fringe plots from the MAC/GMC 4.0 software using MSC/PATRAN, an add-on to the software, known as MACPOST, is needed. MACPOST is distributed with MAC/GMC 4.0 and has its own User Manual (Goldberg *et al*., 1999). As indicated in the MACPOST User Manual, the add-on is capable of generating local and global x-y plots in addition to the fringe plot capabilities illustrated here. An advantage of using PATRAN to generate fringe plots is that a point can be chosen from the macro response at which to examine the micro response via fringe plots. This linkage can be used to gain some additional insight into the local mechanisms that affect the global composite response. The present example problem generates fringe plots for a triply periodic 0.25 volume fraction short fiber SiC/Ti-21S composite subjected to a stress-free cool-down followed by applied transverse strain. The evolution of the J_2 stress invariant and an inelastic strain component are displayed in the fringe plots during application of simulated transverse tensile loading.

MAC/GMC Input File: `example_6b.mac`

```
MAC/GMC 4.0 Example 6b - PATRAN post-processing
*CONSTITUENTS
  NMATS=2
  M=1 CMOD=6 MATID=E
  M=2 CMOD=4 MATID=A
*RUC
  MOD=3 ARCHID=3 VF=0.25 ASP1=2. ASP2=1. DR=1. F=1 M=2
*MECH
  LOP=2 REFTIME=57600.
  NPT=3 TI=0.,57600.,57800. MAG=0.,0.,0.02 MODE=2,1
*THERM
  NPT=3 TI=0.,57600.,57800. TEMP=900.,23.,23.
*SOLVER
  METHOD=1 NPT=3 TI=0.,57600.,57800. STP=40.,1.
*PRINT
  NPL=6
*PATRAN
  TPRE=57600. STP=20
*XYPLOT
  FREQ=5
  MACRO=1
   NAME=example_6b  X=2 Y=8
  MICRO=0
*END
```

Annotated Input Data

1) Flags: None

2) Constituent materials (***CONSTITUENTS**) [KM_2]:

Number of materials:	2	(NMATS=2)
Materials:	SiC fiber	(MATID=E)
	Ti-21S	(MATID=A)
Constitutive models:	SiC fiber: linearly elastic	(CMOD=6)
Ti-21S matrix: Isotropic	GVIPS	(CMOD=4)

3) Analysis type (***RUC**) → Repeating Unit Cell Analysis [KM_3]:

Analysis model:	Triply periodic GMC	(MOD=3)
RUC architecture:	Off-set short fibers, diagonal array	(ARCHID=3)
Fiber volume fraction:	0.25	(VF=0.25)
Fiber aspect ratio:	2.	(ASP1=2.)
Unit cell aspect ratio:	1.	(ASP2=1.)
D ratio:	1.	(DR=1.)
Material assignment:	SiC fiber	(F=1)
	Ti-21S matrix	(M=2)

4) Loading:

a) Mechanical (***MECH**) [KM_4]:

Loading option:	2	(LOP=2)
Strain reference time:	57600. sec.	(REFTIME=57600.)
Number of points:	3	(NPT=3)
Time points:	0., 57600., 57800. sec.	(TI=0.,57600,57800.)
Load magnitude:	0., 0., 0.02	(MAG=0.,0.,0.02)
Loading mode:	stress/strain control	(MODE=2,1)

b) Thermal (***THERM**) [KM_4]:

Number of points:	3	(NPT=3)
Time points:	0., 57600., 57800. sec.	(TI=0.,57600.,57800.)
Temperature points:	900., 23., 23. °C	(TEMP=900.,23.,23.)

c) Time integration (***SOLVER**) [KM_4]:

Time integration method:	Forward Euler	(METHOD=1)
Number of points:	3	(NPT=3)
Time points:	0., 57600., 57800. sec.	(TI=0.,57600.,57800.)
Time step sizes:	40., 1. sec.	(STP=40.,1.)

5) Damage and Failure: None

6) Output:

a) Output file print level (***PRINT**) [KM_6]:

Print level:	6	(NPL=6)

b) PATRAN output (***PATRAN**) [KM_6]:

PATRAN preloading time:	57600. sec.	(TPRE=57600.)
Output step frequency:	20	(STP=20)

Two specifiers control the PATRAN output. A preloading time (`TPRE`) defines the time at which writing of PATRAN output begins. The output time step frequency (`STP`) specifies how often the PATRAN output is written. In the present example, the code writes PATRAN output every 20 time steps starting at time = 57600 sec. Thus, during the 200 time steps occurring during application of the mechanical loading, PATRAN output is written a total of 11 times.

MAC/GMC 4.0 generates 14 PATRAN output ASCII files. These 14 files are:

outfile.macgeo	RUC geometry data
outfile.total_pat.data	Number of time steps and subcells
outfile.macro1_pat.data	RUC level strain data at each output time
outfile.macro2_pat.data	RUC level stress data at each output time
outfile.macro3_pat.data	RUC level inelastic strain data at each output time
outfile.macro4_pat.data	RUC level thermal strain, creep time, temperature, and stress invariant data at each output time
outfile.micro1_pat.data	Subcell level strain data at each output time
outfile.micro2_pat.data	Subcell level stress data at each output time
outfile.micro3_pat.data	Subcell level inelastic strain data at each output time
outfile.micro4_pat.data	Subcell level thermal strain, creep time, temperature, and stress invariant data at each output time
outfile.micro1_pat.contour	Subcell level strain data for fringe plots
outfile.micro2_pat.contour	Subcell level stress data for fringe plots
outfile.micro3_pat.contour	Subcell level inelastic strain data for fringe plots
outfile.micro4_pat.contour	Subcell level thermal strain, creep time, temperature, and stress invariant data for fringe plots

where *outfile* is the name of the MAC/GMC 4.0 output file. In order to employ these ASCII files within PATRAN via MACPOST, all files but the first (*outfile*.macgeo) must be renamed. The leading "*outfile*." must be stripped from the filename. For more information on the MAC/GMC 4.0 PATRAN output capabilities, see the MAC/GMC 4.0 Keywords Manual Section 6. For more information on using MACPOST, see the MACPOST User Guide (Goldberg *et al*., 1999).

c) x-y plots (**`*XYPLOT`**) [KM_6]:

Frequency:	5	(`FREQ=5`)
Number of macro plots:	1	(`MACRO=1`)
Macro plot names:	example_6b	(`NAME=example_6b`)
Macro plot x-y quantities:	ε_{22}, σ_{22}	(`X=2 Y=8`)
Number of micro plots:	0	(`MICRO=0`)

7) End of file keyword: (**`*END`**)

Results

Plotted in Figure 6.4 is the overall (global) transverse stress-strain response of the discontinuous SiC/Ti-21S composite considered in this example problem. Note that this plot is generated from the macro x-y plot file data. The arrows in this figure indicate the six points at which PATRAN fringe plots have been generated. Note that, although only six points have been selected, the PATRAN output files actually contain data for 11 points (i.e., fringe plots have only been generated for every other PATRAN output time).

The fringe plots generated using PATRAN with MACPOST are shown in Figure 6.5 and Figure 6.6. Figure 6.5 shows the evolution of the inelastic strain component corresponding with the direction of the applied loading (ε_{22}^{in}). Each of the six fringe plots shown in this figure were generated individually using the MSC/PATRAN software. Note that these fringe plots were stored as bitmap images, and some manipulation was performed beyond that of the raw PATRAN fringe plot display. Below each fringe plot, the corresponding applied global (composite level) transverse strain at which the inelastic strain component field is plotted is indicated. $\bar{\varepsilon}_{22} = 0$ corresponds to the residual inelastic strain component field in the composite after the applied cool-down but before the application of any simulated mechanical loading. Note that, in this first fringe plot, the subcells that are occupied by the SiC fiber material are outlined in red. This `ARCHID=3` geometry can also be seen in Figure 3.8.

Figure 6.5 indicates that during the cool-down, only the matrix subcells that are between the fibers exhibit noticeable yielding. It is not until the applied global stain reaches 0.008 that the fringe plot shows a noticeable change in the inelastic strain component field. In Figure 6.4, it is clear that this is near the point at which global yielding of the composite is occurring. As the global loading continues to increase, additional subcells yield and the inelastic strain component in the yielded subcells continues to rise. By the end of the applied loading ($\bar{\varepsilon}_{22} = 0.020$), all matrix subcell exhibit noticeable ε_{22}^{in} values, with the inelastic strain component magnitudes being highest in the matrix subcells in between the fibers along the loading direction.

Figure 6.6 shows the evolution of the J_2 stress invariant during the applied global transverse mechanical loading. The J_2 stress invariant is a von Mises type stress and is thus related to the inelastic deformation in the composite. Further, it is a scalar invariant quantity that takes into account all stress components. As the simulated mechanical loading increases, the J_2 stress increases in the composite. The highest magnitude J_2 occurs in the fibers and the matrix in between the fibers. As observed in Figure 6.5, this matrix located in between the fibers exhibits the highest ε_{22}^{in} magnitude as well.

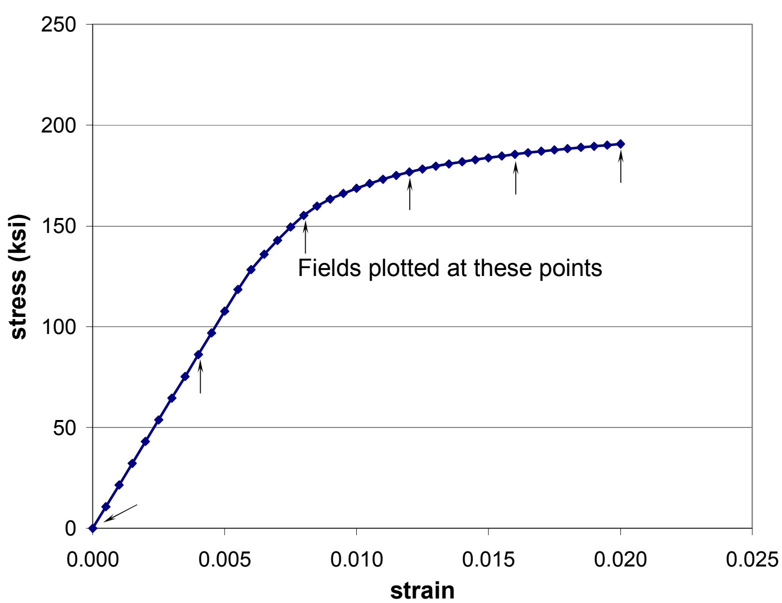


Figure 6.4 Example 6b: Simulated transverse tensile stress-strain response of 25% fiber volume fraction discontinuous SiC/Ti-21S at 23 °C. The arrows indicate the points at which the fields are plotted using the MSC/PATRAN software package in Figure 6.5 and Figure 6.6.

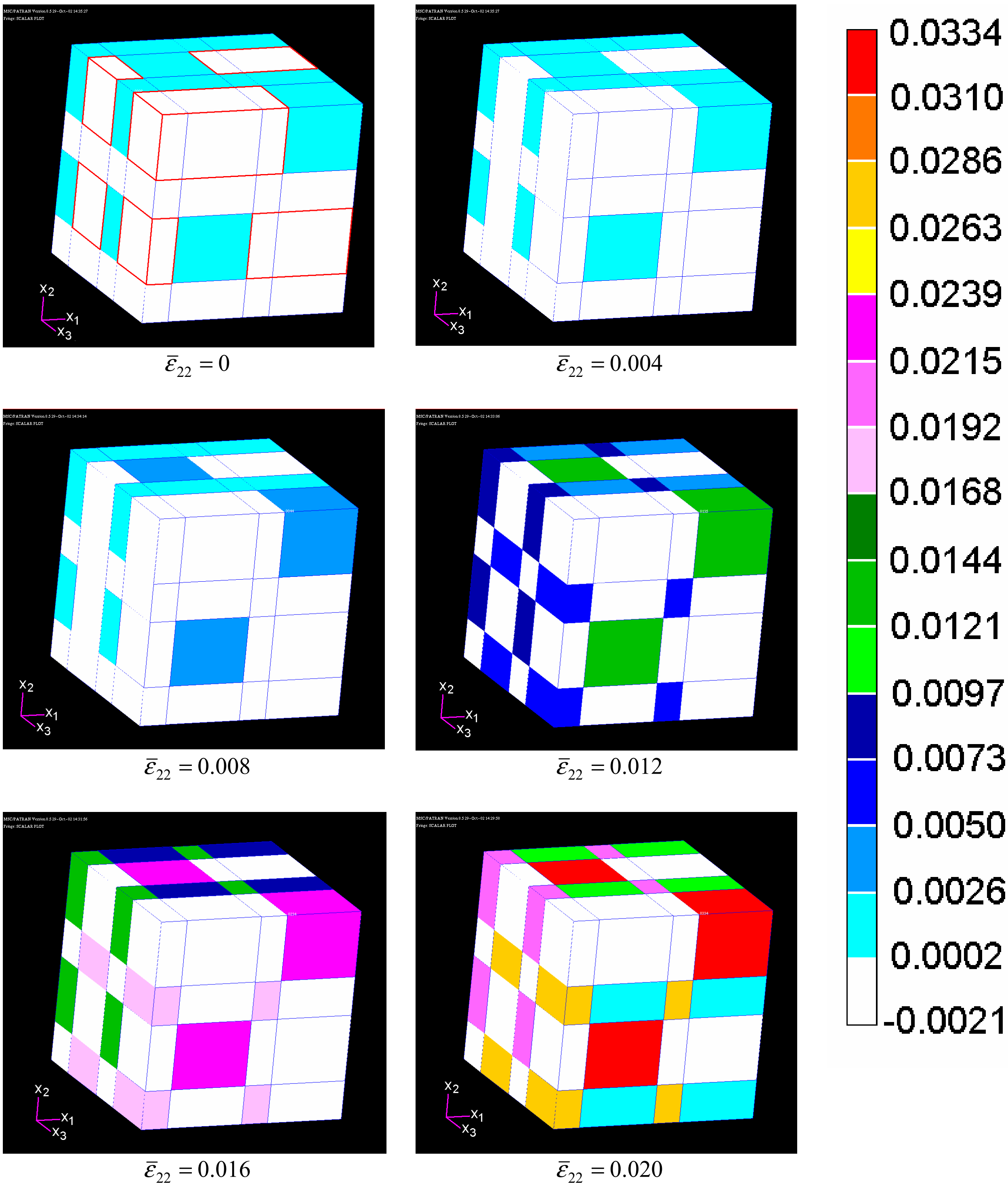
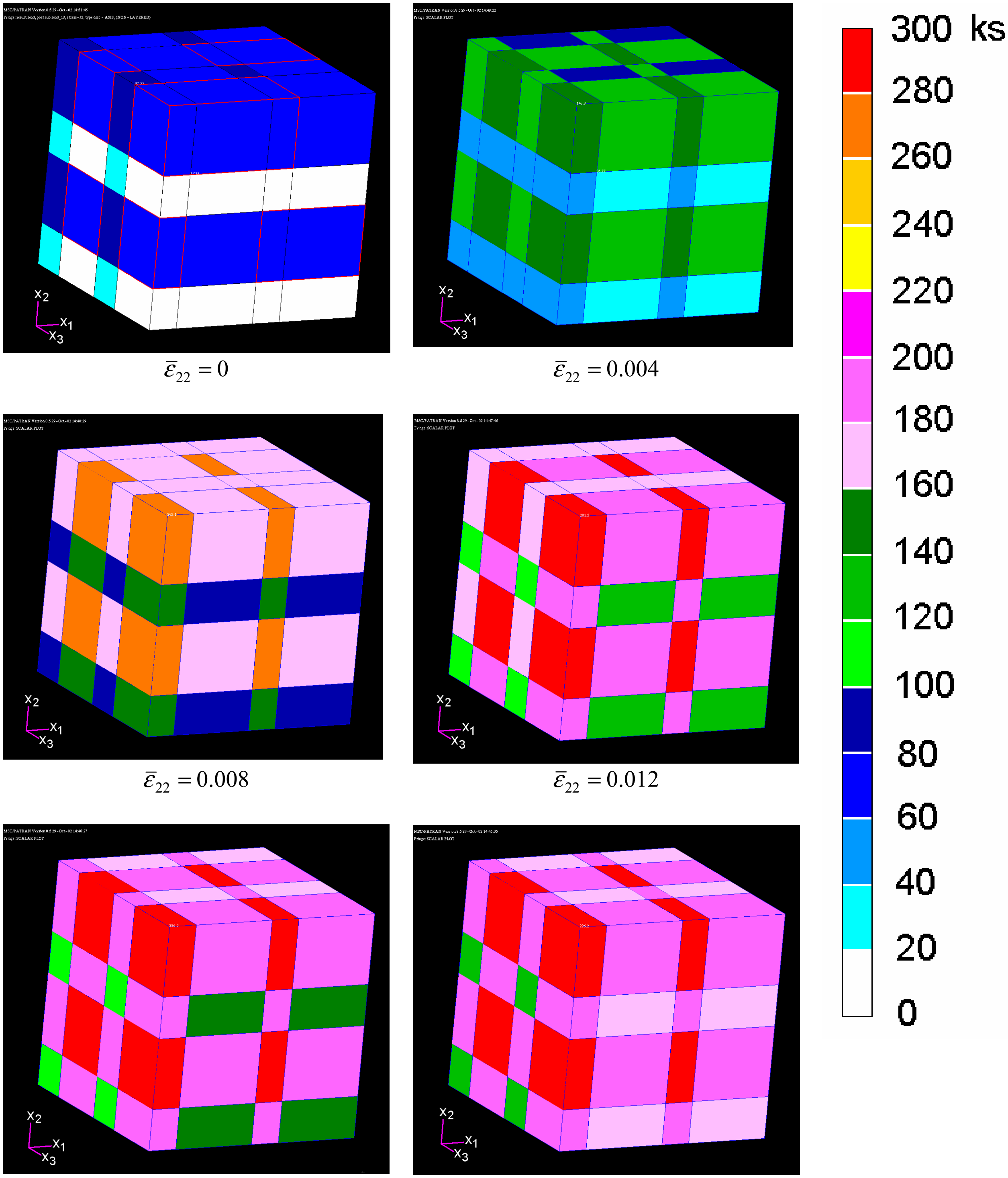


Figure 6.5 Example 6b: Inelastic strain component ε_{22}^{in} at six applied global strain levels for the 25% fiber volume fraction discontinuous SiC/Ti-21S composite at 23 °C as plotted using the MSC/PATRAN software package in conjunction with MACPOST. The fiber subcells are outlined in red in the figure for the lowest applied strain level.



$\bar{\varepsilon}_{22} = 0$ $\bar{\varepsilon}_{22} = 0.004$

$\bar{\varepsilon}_{22} = 0.008$ $\bar{\varepsilon}_{22} = 0.012$

$\bar{\varepsilon}_{22} = 0.016$ $\bar{\varepsilon}_{22} = 0.020$

Figure 6.6 Example 6b: $J_2 = \sqrt{\frac{3}{2} S_{ij} S_{ij}}$ stress invariant at six applied global strain levels for the 25% fiber volume fraction discontinuous SiC/Ti-21S composite at 23 °C as plotted using the MSC/PATRAN software package in conjunction with MACPOST. The fiber subcells are outlined in red in the figure for the lowest applied strain level.